Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation
Federal Higher Authority subordinated to the Ministry of Transport
and Digital Infrastructure

Investigation Report 276/14

Serious Marine Casualty

Collision in the Kiel Firth at Friedrichsort between the MV FRANCISCA and MV RMS BREMEN on 5 September 2014

4 September 2015

The investigation was conducted in conformity with the Law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Act – SUG) of 16 June 2002, amended most recently by Article 1 of 22 November 2011, BGBl. (Federal Law Gazette) I p. 2279.

According to said Law, the sole objective of this investigation is to prevent future accidents and malfunctions. This investigation does not serve to ascertain fault, liability or claims (Article 9(2) SUG).

This report should not be used in court proceedings or proceedings of the Maritime Board. Reference is made to Article 34(4) SUG.

The German text shall prevail in the interpretation of this investigation report.

Issued by:
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1 Summary

At 0211[1] on 5 September 2014, the outbound RMS BREMEN, flying the flag of Cyprus, collided with the inbound FRANCISCA, flying the flag of Antigua & Barbuda, level with the Friedrichsort beacon in Kiel Firth. The exact scene of the collision remains unclear. The AIS recordings of the vessel traffic service indicate that the two vessels clearly passed one another. An electronic chart of the manufacturer and type TRANSAS 4000 was on board both vessels. Recordings of them also indicate that the vessels passed each other.

[1] Unless otherwise stated all times shown in this report are local = Central European Summer Time = UTC + 2 h

2 FACTUAL INFORMATION

2.1 Photo

Figure 1: Photo of the FRANCISCA

2.2 Ship particulars

Name of ship:	FRANCISCA
Type of ship:	General cargo vessel
Nationality/Flag:	Antigua and Barbuda
Port of registry:	Saint John's
IMO number:	9148166
Call sign:	V2CR7
Owner:	Juru Agentura Forsa UAB
Year built:	1997
Shipyard/Yard number:	Scheepswerf Peters B.V./449
Classification society:	DNV GL
Length overall:	89.00 m
Breadth overall:	12.40 m
Gross tonnage:	2,377
Deadweight:	3,452 t
Draught (max.):	4.9 m
Engine rating:	1,290 kW
Main engine:	Anglo Belgian 8MDZC-800-173
(Service) Speed:	11.0 kts
Hull material:	Steel
Hull design:	Double bottom
Minimum safe manning:	6

2.3 Voyage particulars

Port of departure:	Klaipėda
Port of call:	Kiel Canal, Honfleur
Type of voyage:	Merchant shipping, international
Draught at time of accident:	5.1 m
Manning:	6
Pilot on board:	No

Figure 2: Photo of the RMS BREMEN

2.4 Ship particulars

Name of ship:	RMS BREMEN
Type of ship:	Multipurpose dry cargo vessel
Nationality/Flag:	Cyprus
Port of registry:	Limassol
IMO number:	9617301
Call sign:	5BLX3
Owner:	Hermann Lohmann Bereederungen
Year built:	2012
Shipyard/Yard number:	Slovenske Lodenice Komarno/3802
Classification society:	DNV GL
Length overall:	89.88 m
Breadth overall:	12.80 m
Gross tonnage:	2,589
Deadweight:	3,812 t
Draught (max.):	5.5 m
Engine rating:	1,520 kW
Main engine:	Caterpillar 8M20C
(Service) Speed:	12 kts
Hull material:	Steel
Hull design:	Double bottom
Minimum safe manning:	6

2.5 Voyage particulars

Port of departure:	Kiel Canal outbound
Port of call:	Szczecin
Type of voyage:	Merchant shipping, international
Draught at time of accident:	5.6 m
Manning:	6
Pilot on board:	No

2.6 Marine casualty or incident information

Type of marine casualty or incident:	Serious marine casualty, collision
Date, time:	05/09/2014 0211
Location:	Kiel Firth, Friedrichsort
Latitude/Longitude:	φ 54°23.3'N λ 010°11.8'E
Ship operation and voyage segment:	Harbour mode
Place on board:	Fore sections
Human factors:	Yes, violation
Consequences (for people, ship, cargo, environment, other):	Superficial damage to both vessels None

Excerpt from Nautical Chart 34, BSH

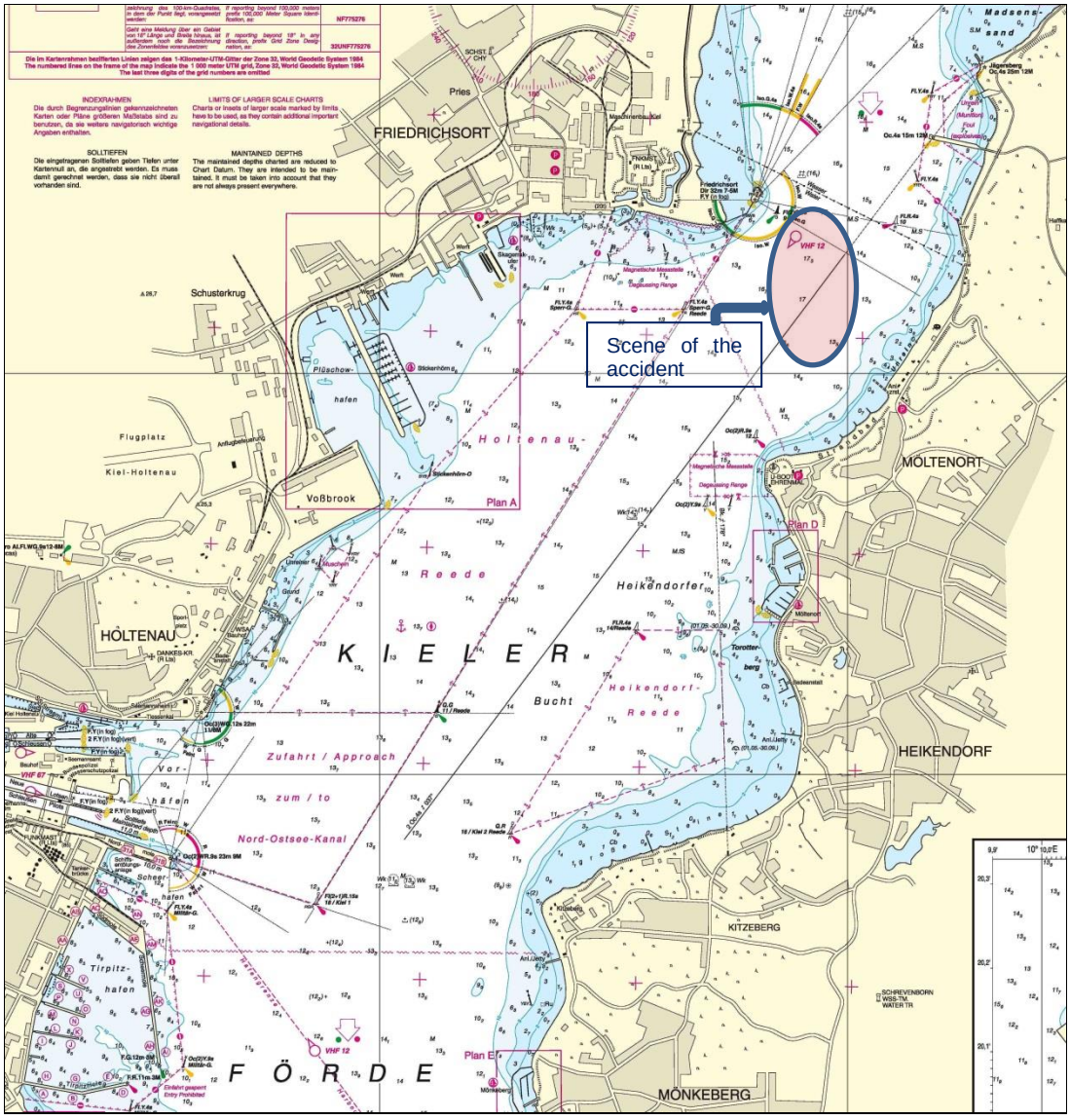

Figure 3: Nautical chart

2.7 Shore authority involvement and emergency response

Agencies involved:	Waterway Police (WSP) Kiel
Resources used:	None
Actions taken:	Anchored
Results achieved:	Survey of damage

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

The RMS BREMEN left the Kiel Canal's Neue Südschleuse (new south lock) in easterly winds of 4 Bft, light swell, and good visibility at 0155. The master and chief officer were on the bridge in the role of officer on watch (OOW) and helmsman, respectively. The course was reportedly altered to 078° at 0158 and to 037° at 0201 at a speed of 9 kts on the leading light line. The red light buoy was reportedly steered for close to the starboard side during the approach to the Friedrichsort narrows and as Friedrichsort lighthouse was abeam there was the last chance for FRANCISCA to avoid the collision by a manoeuvre. The FRANCISCA approached from the north. When she came into view with masthead lights and green sidelight on the port side at a distance of some 0.5 nm from Friedrichsort lighthouse, she was reportedly called on VHF and a whistle signal was sounded. It was reported that there was no response from the FRANCISCA. The collision with the FRANCISCA then occurred on a level with Friedrichsort lighthouse. By all accounts, it was narrow off Friedrichsort and a course alteration to starboard was reportedly out of the question for the RMS BREMEN due to the supposedly high degree of damage in the vicinity of the engine room. The RMS BREMEN was first damaged on the port bow, then amidships, and finally aft on the steps.

The FRANCISCA steered for the Friedrichsort lighthouse from the north. According to reports given, only the chief officer was on the bridge when the collision occurred. Two able bodied seamen were on deck making preparations for entering the Kiel lock. The second seaman was reportedly woken about five minutes before the collision to help on the forecastle. The lookout was reportedly assigned to the navigational watch from 2200 to 0200. By all accounts, he was instructed to go to the forecastle to make ready the mooring lines for the port side at 0145. When he opened the hatch on the forecastle, he reportedly saw a vessel with two masthead lights and a red sidelight coming towards him. He reportedly warned his colleague, who was standing at the winch on the starboard side. The distance to the vessel reportedly dropped rapidly. By all accounts, one seaman ran towards the stern. The other seaman reportedly stood behind the foremast when the collision happened. After the collision, the other vessel involved reportedly parted without issuing any light or whistle signals. At the same time, the seaman standing amidships reportedly went to his colleague on the forecastle and spoke to him. According to reports given, he just managed to jump behind the foremast and reportedly remained uninjured. He reportedly heard no signals to attract attention before the collision. The two seamen then inspected the deck and cargo hold for damage. It was claimed that the FRANCISCA then anchored at the Holtenau roadstead with three shackles of chain length deployed. The chief officer reportedly just carried out a course alteration from 187° to 213° abeam the Friedrichsort beacon and reduced the speed to SLOW AHEAD as the FRANCISCA have collided with the RMS BREMEN at the position 54°23.355 N 010°11.887' E (see Figs. 5 and 6) at 0211. Nothing was reportedly undertaken on the RMS BREMEN to implement a safe passage. There was reportedly no reduction in speed and the course was not altered to starboard. It was

claimed that she actually altered her course to port to begin with. It was reported that nobody responded to the VHF call of the FRANCISCA. The heading was reportedly 232° when the collision happened, while the FRANCISCA reportedly turned further to starboard.

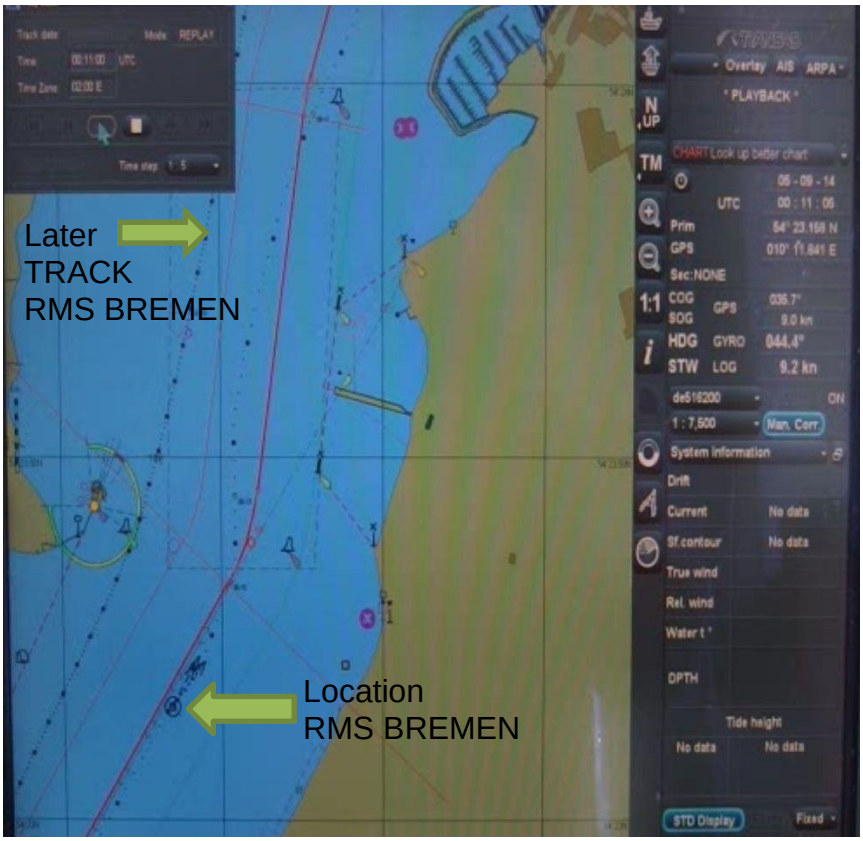

Figure 4: RMS BREMEN's ECS – scene of the collision at 021105

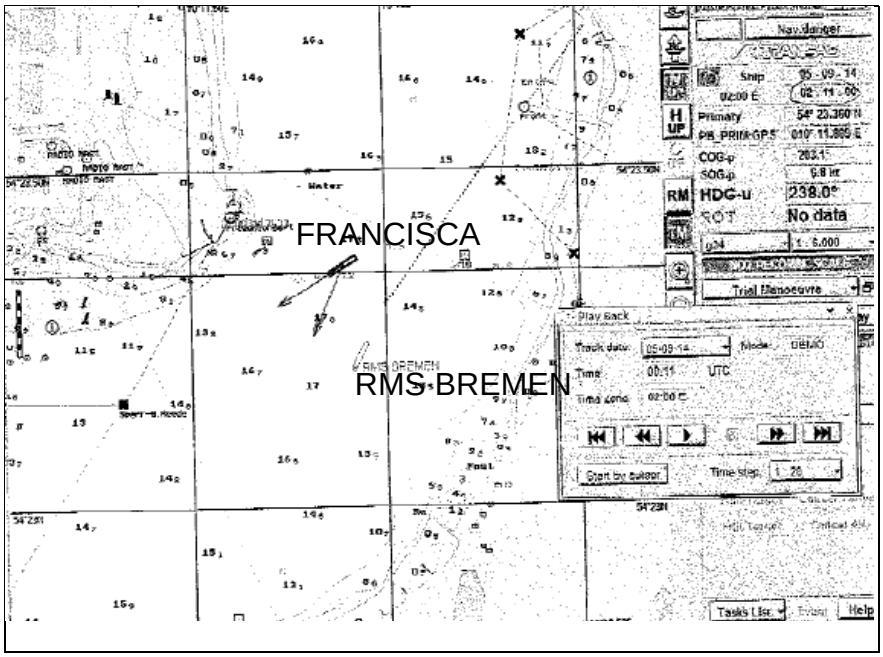

Figure 5: FRANCISCA's ECS – scene of the collision at 021100

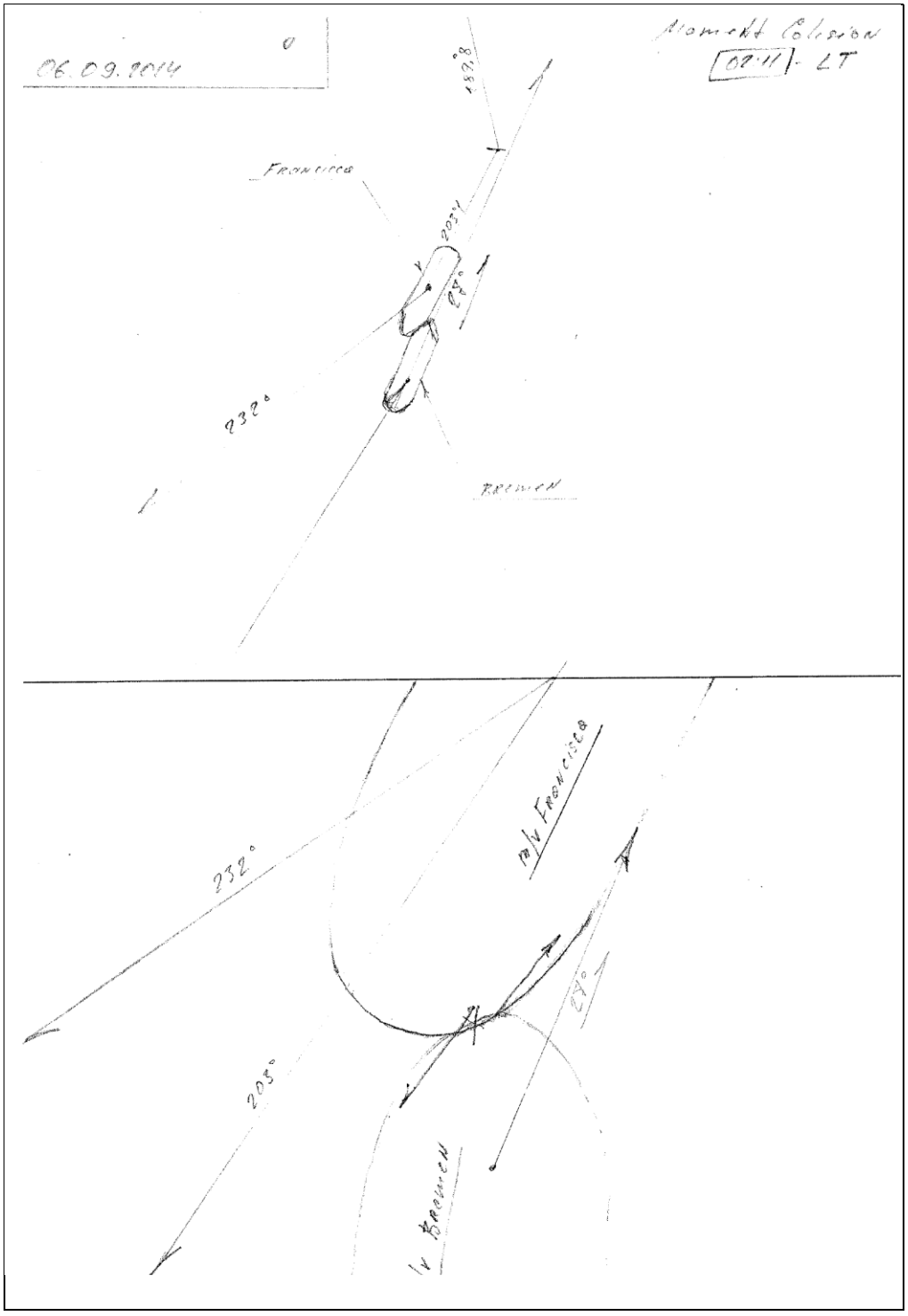

Figure 6: Drawing made on the FRANCISCA – collision angle at 0211

3.2 Investigation

Neither the reproduction of the electronic charts nor the drawing made on the FRANCISCA provide insight into the exact scene of the collision. Only the time of the collision is consistent. At 021105, the RMS BREMEN is located far to the south-east of the Friedrichsort beacon, while the drawing made on the FRANCISCA indicates that the scene of the collision is shortly after the planned course alteration at the beacon. Consequently, the BSU requested radar and AIS recordings from Vessel Traffic Service Travemünde. Regrettably, no radar recordings were available, as they are deleted in the ring buffer after about a month. Consequently, there was no second system to verify the GPS and AIS data. A type-tested GPS receiver was installed on board each vessel. The accuracy of the GPS positions received is 8-13 m. DGPS receivers, which can fine tune GPS positions to about 3 m, were not installed. The AIS data recorded by the vessel traffic service were forwarded to the Federal Waterways Engineering and Research Institute (BAW) in Hamburg for analysis. The BAW confirmed that no collision would have occurred according to the data pool, which indicated that the vessels would have passed one another at too wide a berth.

The data analysis by Vesseltracker at the instigation of Waterway Police Kiel yielded the same findings as the BAW. There was evidently a GPS error. The damage is indicative of an acute collision angle at the two forecastles. The FRANCISCA scraped down the port side of the RMS BREMEN.

Figure 7: Damage to the FRANCISCA

Figure 8: Damage to the RMS BREMEN

The classification society DNV GL surveyed the two vessels after the collision. Moreover, the Ship Safety Division (BG Verkehr) conducted a port State control in accordance with the Paris Memorandum of Understanding. The FRANCISCA was issued a detention order and the RMS BREMEN was permitted to proceed, subject to conditions, to a shipyard within internal waters.

The fore section of the FRANCISCA was cracked, buckled, and dented above the waterline on the shell plating between the bow and frame 130. She also exhibited deformations on the port side of the bulwark. The forecastle's watertight integrity was impaired. The detention order was issued because the officers on watch did not observe the hours of rest, drills and exercises were not shown in the time sheets, and there were inconsistencies between the watchkeeping plan for lookouts and the hours of work in port. On a six-by-six-hour-cycle, there were no adequate hours of rest possible in a two-watch system (one of which at least six continuous hours) for the master and chief officer. On 1 Aug., 2 Aug., 23 Aug. and 24 August the rest hours of one able bodied seamen were interrupted three times and less than 6 hours. The rest hours on days with fire and boat drills were not recorded. An audit of the flag State according to the safety management system and the ISM Code was absent. An emergency exit to the aft weather deck was locked and could not be opened. The detention order was lifted on 15 September 2014 and the FRANCISCA was able to proceed, subject to conditions, to a shipyard within internal waters.

The fore section of the RMS Bremen was buckled and cracked on the bulwark and shell plating above the waterline between the bow and frame 113 on the port side. The seals and air pipes on the tanks were buckled, cracked or destroyed. The deck was dented between frames 68 and 72 and the weld between a bollard and the deck was damaged. The aft deck was dented and cracked between frames 11 and 20. The guard rail on the port side was destroyed along its entire length. The bow thruster was damaged and watertight integrity was impaired in the fore section, bow thruster room, and superstructure. The RMS BREMEN was permitted to proceed, subject to conditions, to the closest shipyard within internal waters. In contrast to the FRANCISCA, a five-by-seven-hour watchkeeping plan was kept on the RMS BREMEN. This means that from a procedural point of view it was possible to observe the hours of rest with the same manning as the FRANCISCA.[2]

[2] The watchkeeping plan must be consistent with the Seafarers' Hours of Work and the Manning of Ships Convention. The limits on hours of work are as follows: (a) maximum hours of work shall not exceed: (i) 14 hours in any 24-hour period; and (ii) 72 hours in any seven-day period; or (b) minimum hours of rest shall not be less than: (i) ten hours in any 24-hour period; and (ii) 77 hours in any seven-day period. Hours of rest may be divided into no more than two periods, one of which shall be at least six hours in length, and the interval between consecutive periods of rest shall not exceed 14 hours.

4 ANALYSIS

Verification of the GPS data by means of a second independent system was not possible due to the lack of radar recordings of the vessel traffic service. Therefore, the AIS data were analysed by two different service providers: a Hamburg-based company called Vesseltracker and the Federal Waterways and Shipping Administration (WSV) in Brunsbüttel. Each has a separate receiving station. AIS data from WSP Cuxhaven (Joint Control Centre of the Waterway Police of the Coastal States) were not available on this occasion due to a faulty data cable. They would have complied with the WSV's data, as a visit by the BSU to the Control Centre on 28 January 2015 revealed. An earlier time displacement error in the AIS data received, which the BSU was aware of, has now been remedied by installing a time server. In the case of the AIS data protocol, it should be noted that only the seconds are transmitted. Consequently, a full timestamp must be generated when receiving and storing AIS data to make it possible to assign the data later on. About four hours after the collision, both ships were in the vicinity of the scene of the collision at the pier in Scheerhafen, Kiel. The BAW was unable to find any significant anomalies during the analysis there.

4.1 AIS data analysis by Vesseltracker and the BAW

The scene of the collision does not correlate with the time. At 0211, the time of the collision, the southerly proceeding FRANCISCA and the northerly proceeding RMS BREMEN were far apart and passed one another without touching according to the AIS recordings.

Figure 9: Chart from Vesseltracker made using OpenStreetMap

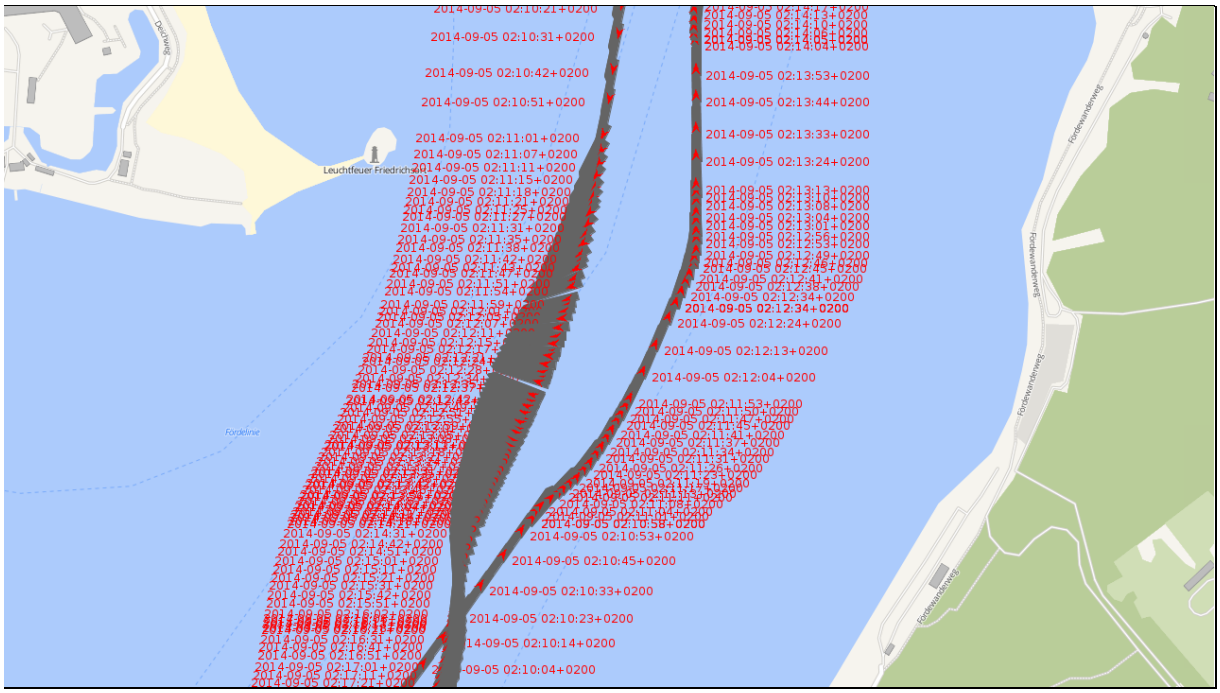

Figure 10: Chart from Vesseltracker, time lapse

The following table is based on Vesseltracker's analysis of the received AIS data. The time of the collision is marked red. The positions in degrees/decimal are far

apart. SOG refers to the speed over ground, COG to the course over ground, and HDG to the heading. The course and speed data indicate that the collision happens at 021101. The RMS Bremen's HDG alters to 3° and the FRANCISCA's to 15°. The FRANCISCA's SOG alters markedly by 0.3 kts. The calculated distance between the GPS antenna on each vessel is 566 m. The COGs are based on the GPS receiver and hardly change.

RMS BREMEN						FRANCISCA					
UTC+2	Latitude N	Longitude E	SOG	COG	HDG	UTC+2	Latitude N	Longitude E	SOG	COG	HDG
02:06:04	54,375110	10,183492	9,6	38	37	02:06:01	54,403873	10,200657	9,6	184	181
02:06:14	54,375495	10,184010	9,6	38	36	02:06:11	54,403475	10,200585	9,6	184	182
02:06:23	54,375810	10,184427	9,6	37	36	02:06:22	54,402988	10,200503	9,6	183	183
02:06:33	54,376165	10,184887	9,6	36	36	02:06:31	54,402590	10,200438	9,6	183	184
02:06:43	54,376520	10,185347	9,6	36	35	02:06:40	54,402192	10,200377	9,6	183	185
02:06:53	54,376882	10,185808	9,6	36	35	02:06:51	54,401660	10,200295	9,6	184	181
02:07:04	54,377288	10,186302	9,6	36	35	02:07:01	54,401218	10,200222	9,7	185	177
02:07:14	54,377652	10,186750	9,6	35	35	02:07:07	54,400997	10,200185	9,6	185	175
02:07:23	54,377978	10,187153	9,6	36	36	02:07:11	54,400775	10,200150	9,6	184	173
02:07:34	54,378343	10,187610	9,6	36	36	02:07:15	54,400642	10,200130	9,6	183	173
02:07:43	54,378700	10,188063	9,7	36	36	02:07:17	54,400510	10,200110	9,6	183	172
02:07:53	54,379058	10,188520	9,7	36	35	02:07:21	54,400377	10,200092	9,6	182	172
02:08:04	54,379453	10,189020	9,7	36	35	02:07:25	54,400200	10,200068	9,6	181	172
02:08:14	54,379815	10,189475	9,7	36	35	02:07:27	54,400112	10,200058	9,6	181	171
02:08:23	54,380143	10,189882	9,7	35	35	02:07:31	54,399890	10,200033	9,6	180	171
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02:08:53	54,381230	10,191242	9,7	35	35	02:08:01	54,398607	10,199957	9,5	175	186
02:09:04	54,381630	10,191742	9,7	35	35	02:08:08	54,398297	10,199950	9,4	176	191
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02:10:53	54,385557	10,196707	9,6	36	35	02:08:43	54,396723	10,199848	9,1	189	194
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02:10:58	54,385713	10,196962	9,3	41	41	02:09:01	54,395993	10,199725	9,2	192	186
02:11:01	54,385823	10,197058	9,0	35	44	02:09:08	54,395652	10,199655	9,2	192	184
02:11:04	54,385887	10,197147	8,9	36	44	02:09:11	54,395523	10,199628	9,2	192	184
02:11:08	54,385977	10,197372	8,6	47	42	02:09:14	54,395438	10,199610	9,2	191	183
02:11:11	54,386063	10,197580	8,5	50	40	02:09:17	54,395310	10,199582	9,2	191	183
02:11:13	54,386115	10,197673	8,4	49	37	02:09:21	54,395138	10,199545	9,2	190	183
02:11:17	54,386188	10,197822	8,4	49	35	02:09:25	54,394967	10,199508	9,2	190	183
02:11:19	54,386260	10,197973	8,4	50	33	02:09:28	54,394797	10,199473	9,2	189	183
02:11:23	54,386370	10,198155	8,3	46	31	02:09:31	54,394668	10,199447	9,2	189	183
02:11:26	54,386455	10,198273	8,2	44	29	02:09:42	54,394240	10,199362	9,2	187	184
02:11:31	54,386575	10,198428	8,1	41	28	02:09:51	54,393813	10,199280	9,3	186	186
02:11:34	54,386667	10,198537	8,0	38	27	02:10:01	54,393428	10,199207	9,3	186	189

02:11:37	54,386792	10,198667	8,0	34	27	02:10:11	54,392958	10,199118	9,3	186	191
02:11:41	54,386888	10,198762	8,0	33	27	02:10:21	54,392532	10,199033	9,4	187	192
02:11:45	54,387013	10,198893	8,0	31	26	02:10:31	54,392147	10,198950	9,4	189	192
02:11:47	54,387107	10,198992	8,0	31	26	02:10:42	54,391673	10,198840	9,4	190	191
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02:12:13	54,388008	10,199757	8,3	26	22	02:11:11	54,390433	10,198522	8,6	192	215
02:12:24	54,388363	10,200045	8,4	26	19	02:11:15	54,390267	10,198473	8,4	194	218
02:12:34	54,388572	10,200237	8,4	27	15	02:11:18	54,390103	10,198423	8,2	195	221
02:12:34	54,388572	10,200237	8,4	27	15	02:11:21	54,389983	10,198385	8,0	196	223
02:12:34	54,388572	10,200237	8,4	27	14	02:11:25	54,389863	10,198345	7,8	197	226
02:12:34	54,388712	10,200352	8,4	26	12	02:11:27	54,389785	10,198318	7,6	199	227
02:12:38	54,388855	10,200465	8,4	25	8	02:11:31	54,389628	10,198263	7,3	200	231
02:12:41	54,388953	10,200538	8,4	24	5	02:11:35	54,389477	10,198207	7,0	202	234
02:12:45	54,389093	10,200623	8,3	21	0	02:11:38	54,389363	10,198162	6,9	202	236

Figure 11: Table showing course of the voyage

The BAW analysis shows the COG/SOG vectors at the time of the collision. The GPS receiver worked properly on each vessel, as can be seen from the reference positions in Fig. 13 with electronic chart.

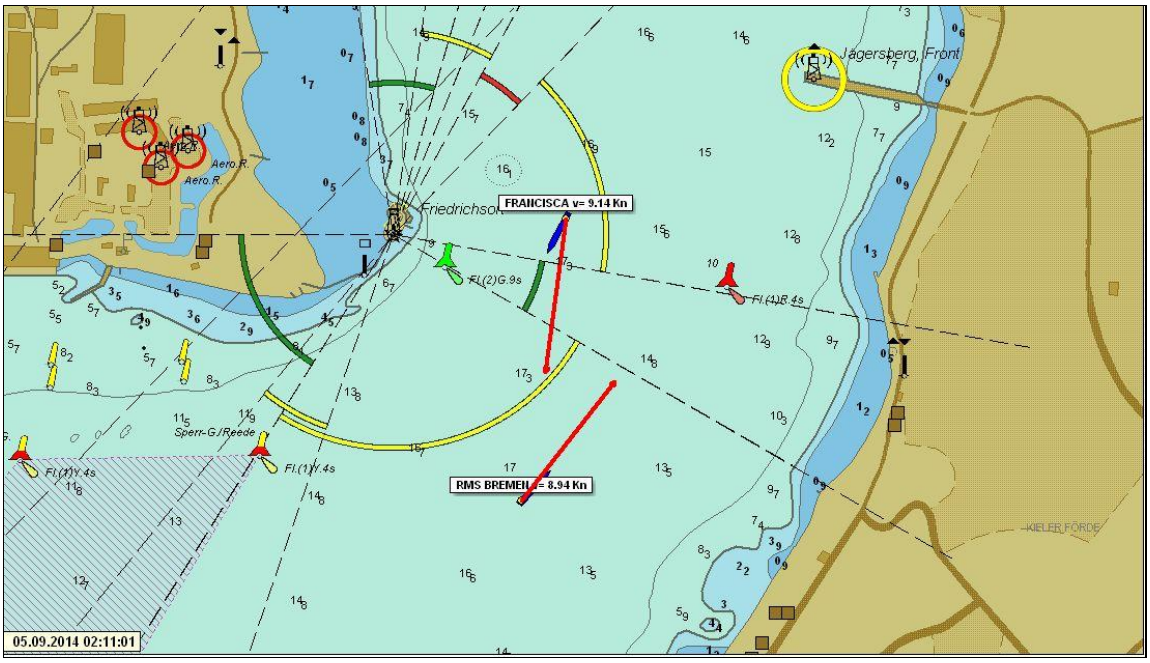


Figure 12: Scene of collision as per AIS with electronic chart, BAW

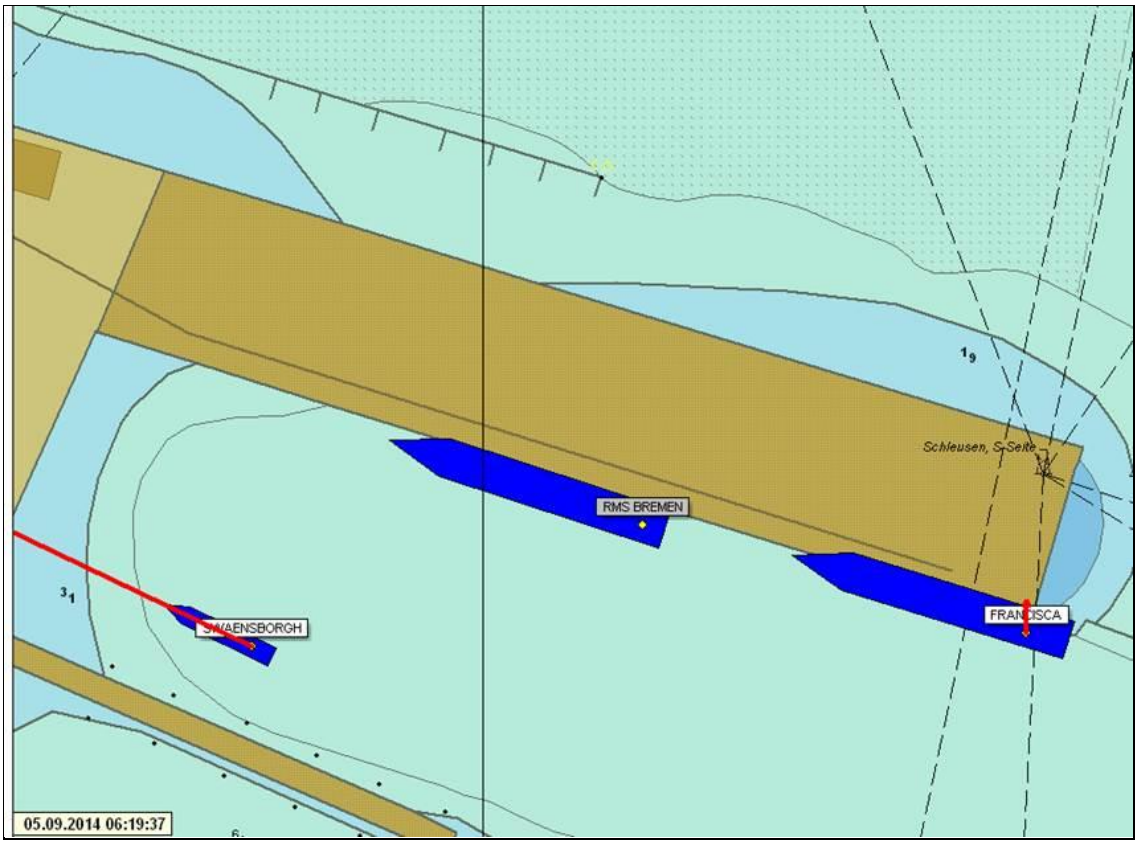
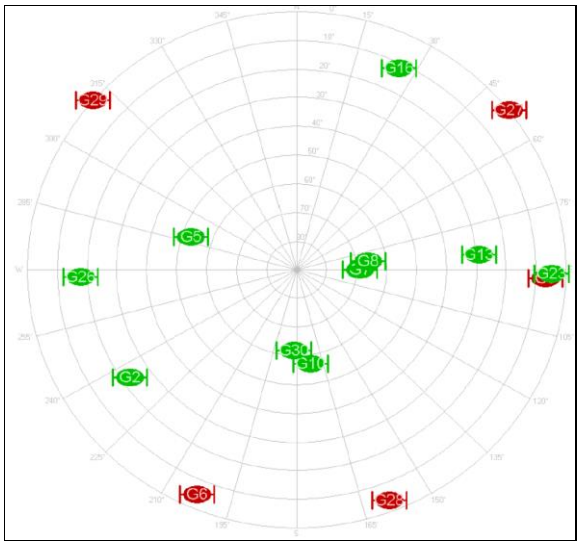


Figure 13: GPS reference, Scheerhafen, Kiel, BAW

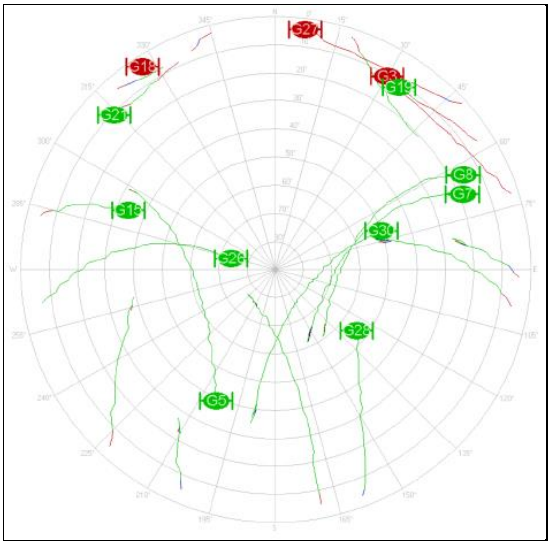
4.2 GPS assessment of the Federal Maritime and Hydrographic Agency (BSH)

The BSH reconstructed and analysed on behalf of the BSU the satellite constellation for the scene and time of the accident on its simulator used for the type examination for GPS receivers.

Figure 14: Satellite constellation



GPS satellite constellation
at 0000 UTC on 05/09/2014



GPS satellite constellation
at 0200 UTC on 05/09/2014

Simulated situation at the scene of the accident based on the GPS Observation Archive of the United States Coast Guard (USCG NavCen), GPS Satellite Almanac of 4/5 September 2014 (http://www.navcen.uscg.gov). The height of the satellites marked red is less than 10° above the horizon.

The Coast Guard (USCG) released the following general message on the usability of the GPS satellites SVN35/PRN03 for 5 September 2014:

NOTICE ADVISORY TO NAVSTAR USERS (NANU) 2014069 NANU TYPE: GENERAL
*** GENERAL MESSAGE TO ALL GPS USERS ***
ON APPROXIMATELY 05 SEP 2014 SVN35 WILL RESUME TRANSMITTING L-BAND UTILIZING PRN03. AT L-BAND ACTIVATION, SVN35/PRN03 WILL BE UNUSABLE UNTIL FURTHER NOTICE. ADDITIONALLY, NO BROADCAST ALMANACS WILL INCLUDE SVN35/PRN03 UNTIL FURTHER NOTICE.
*** GENERAL MESSAGE TO ALL GPS USERS ***

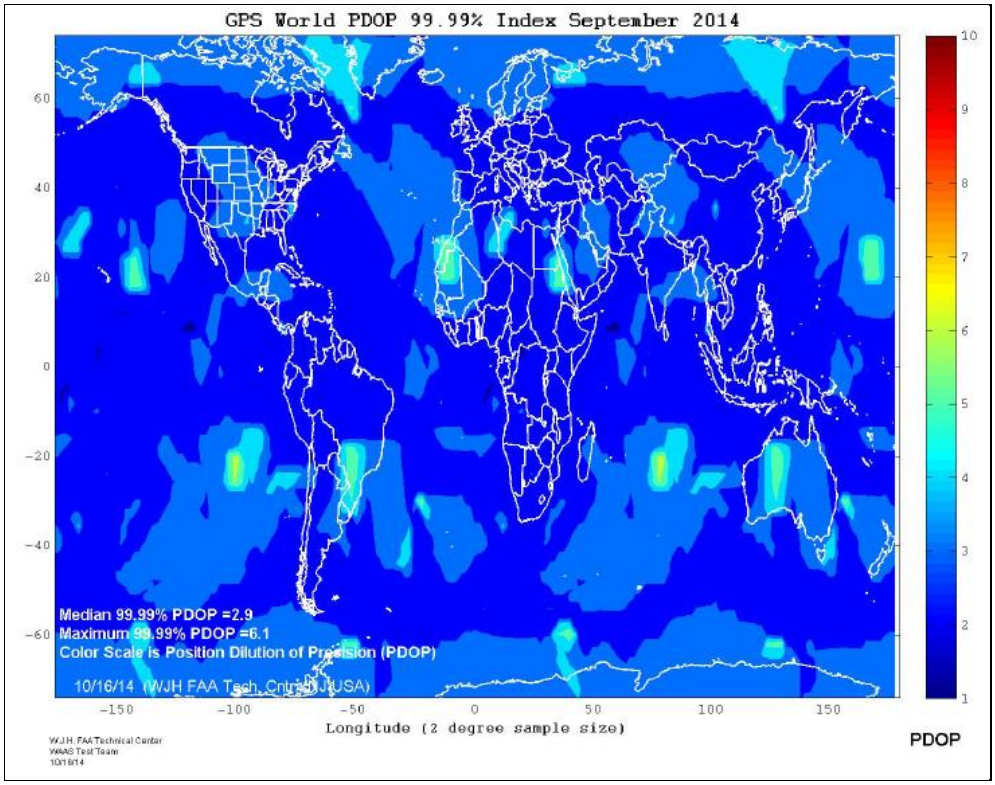


Figure 15: PDOP measurement

Position dilution of precision (PDOP) world map (parameter to assess the accuracy of a three-dimensional GPS measurement). The PDOP value for Kiel Firth is between one and two, meaning accuracy was high.

Horizontal dilution of precision (HDOP – parameter to assess the accuracy of a two-dimensional GPS measurement), 05/09/2014 – 0000-0300 UTC (Hemisphere GNSS receiver recording). The HDOP value stood at 0.8 at the time of the collision, meaning accuracy at the scene of an accident was high.

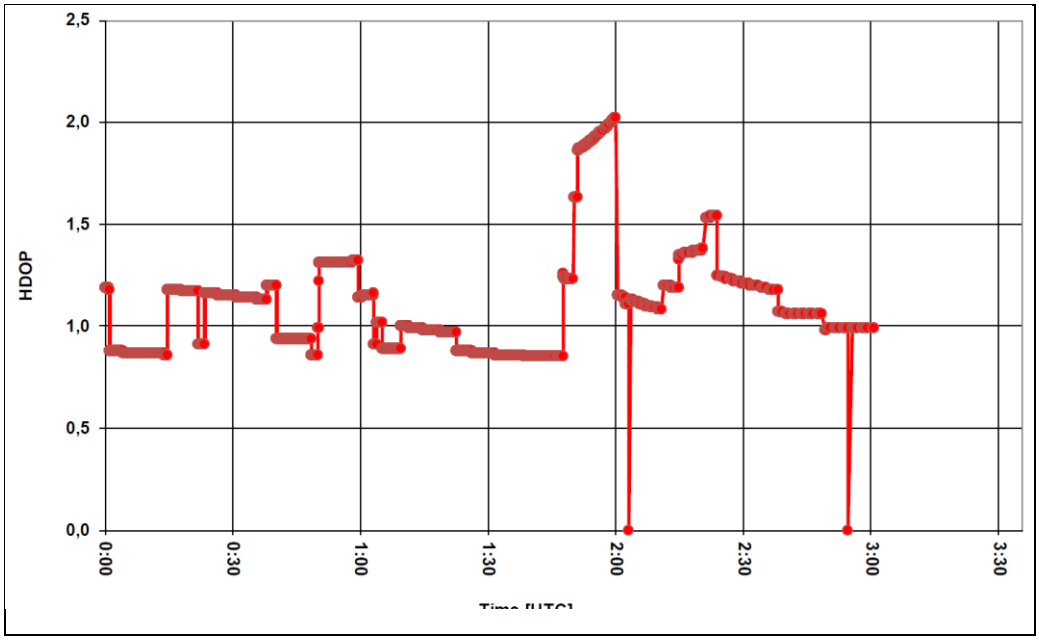


Figure 16: HDOP measurement

A slight deterioration of the available satellite constellation at about 0200 UTC in the vicinity of the scene of the accident is apparent in the simulation. It is not sufficient to explain deviations of more than 20 m, however. Two GPS receivers type tested for maritime shipping did not exhibit any failures or anomalies.

As regards the underlying satellite constellation, one other source of error would be that shadowing of the ship's GPS antenna (by the funnel or superstructure, for example) could cause further significant deterioration. GPS receivers approved for shipping warn the user with an alarm if the satellite constellation deteriorates and an HDOP of four is exceeded. Further isolation is impossible without access to GPS output data. Data from the GPS receiver could be obtained if VDR recordings were available. All standard NMEA data records of the GPS include HDOP values and the number of satellites used. This enables an understanding of any assumptions made about possible shadowing and ensuing positional errors.

The data that underlie the simulation merely describe the GPS system status with its satellite constellation and the satellites over the Kiel Firth that were available for use on the night of 4-5 September 2014, but not the reception conditions at the site of the antenna on the ship at the time of the accident. These data are only available in the GPS receiver concerned and the output stations connected to it, such as a VDR. It would then also be evident if the GPS receiver issued a usage warning.

4.3 DGPS assessment by the Traffic Technologies Centre of the WSV

The Traffic Technologies Centre assessed on behalf of the BSU the recorded AIS data of the vessels at the scene of the accident using the WSV's differential global positioning system (DGPS) reference stations based on the correction parameters. It was merely possible to verify whether there was a GPS malfunction at the monitor stations on the Kiel Canal or at the reference station in Zeven. Permanently recorded data from the Groß Königsförde monitor stations on the Kiel Canal were analysed for this purpose.

It is **not** possible to make an ex-post verification of the GPS signals received on the ships without additional measurement data. Indeed, the reference stations do record GPS correction parameters for the received satellites. However, they could only be applied during the follow-up stage if the ships involved in the accident also recorded the pseudoranges[3] for each satellite. Consequently, it is not possible to make a verification using the computed and recorded positions alone.

[3] Pseudorange refers to the first approximation of distance between a GPS transmitter and a GPS receiver based on the duration of the radio signal.

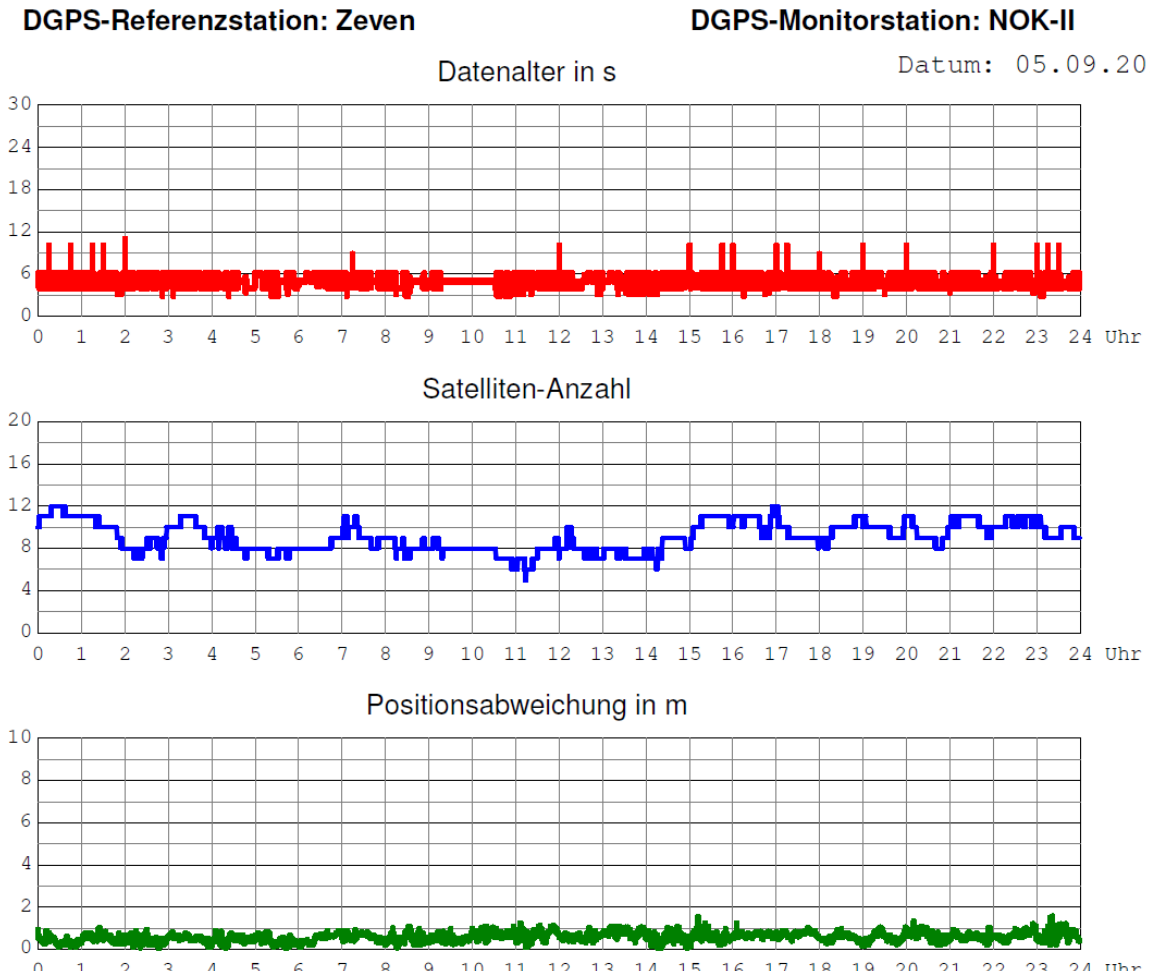


Figure 17: DGPS measurement

The analyses show the DGPS measurements made in the course of a typical day on a standard receiver. No anomalies are evident. The maximum positional error (scatterplot) was only 1.58 m on 5 September 2014.

No abnormalities in the GPS satnav system were found at the monitor stations located further away from the scene of the accident on 5 September 2014, either. It was not possible to find any evidence of interference caused by interstellar winds or intentional manipulation[4], for example.

[4] Interstellar winds and intentional manipulation due to interfering signals (jamming) can lead to a system blackout or be used specifically for position falsification (spoofing). A global navigation satellite system (GNSS) operates on a frequency of about 1.5 GHz and transmits at an output of about 50 watts per satellite, which attenuates to microwatt level by the time it reaches the receiver on the ground. Low output is not enough to disrupt a GNSS. For comparison, a terrestrial navigation system like LORAN operates on the frequency 100 kHz and transmits at an output of about 250 kW.

4.4 Current patterns – Kiel University, BAW, BSH

In September 2013, Kiel University published the final report on hydrological as well as morpho-sedimentological field measurements in the Kiel Firth. The following measurements were made in the Friedrichsort narrows on 4 May 2013.

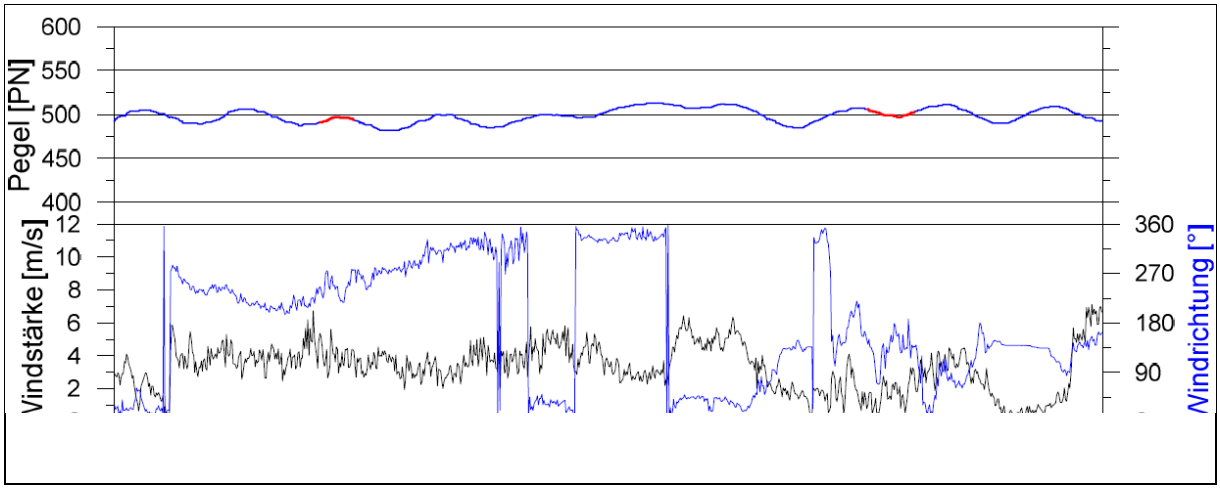


Figure 18: Wind and water level measurement

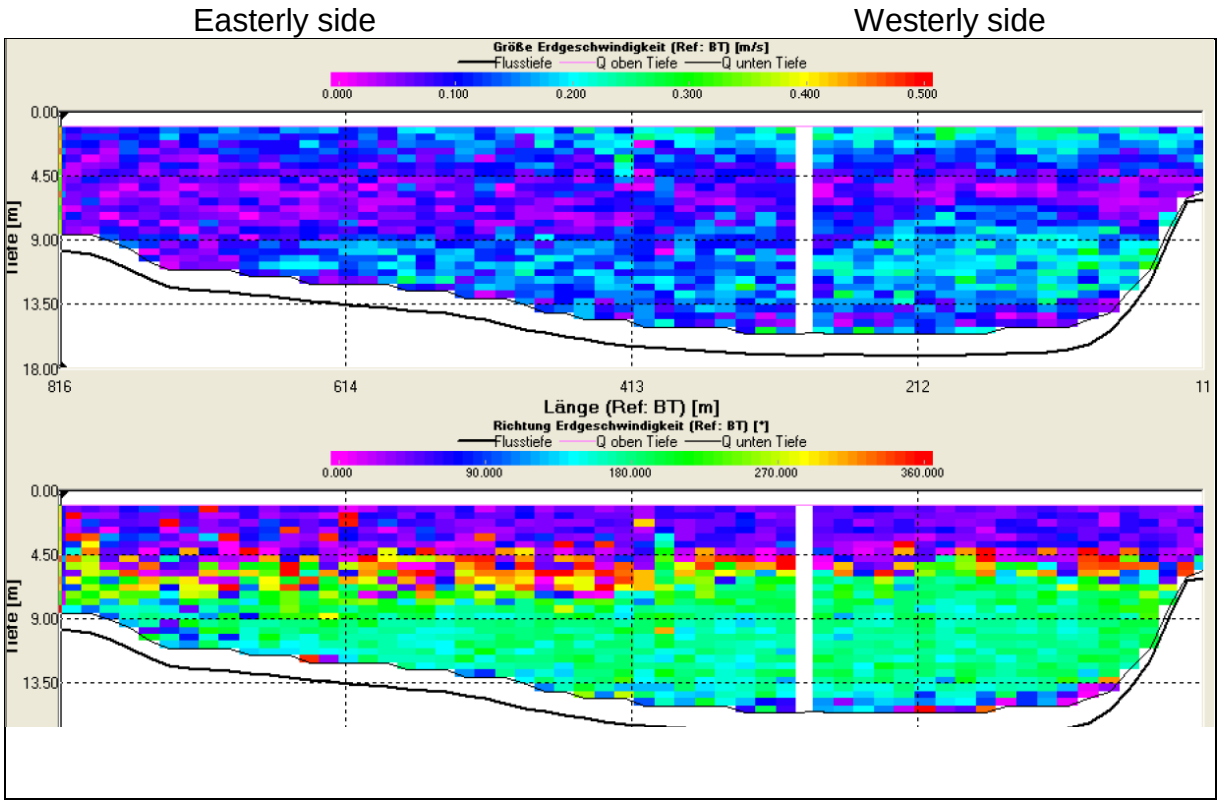


Figure 19: Current measurement in the Friedrichsort narrows on 4 May 2012

In contrast to the day of the accident, the wind and water level patterns were affected by WSW winds of force 5 Bft. The water level deviated from the ordnance data only marginally. The measurement readings made on that day indicated that in addition to a typical circulation pattern in the north/south direction of the Kiel Firth, a second wind-induced circulation system had formed, where water masses flowed at a low speed from west to east on the surface and in the opposite direction on the bottom. At a maximum measurement of 30 cm/s, the current velocity in the westerly part of the Kiel Firth is somewhat stronger than in the easterly part. Whether the situation changes or reverses in easterly winds was not investigated.

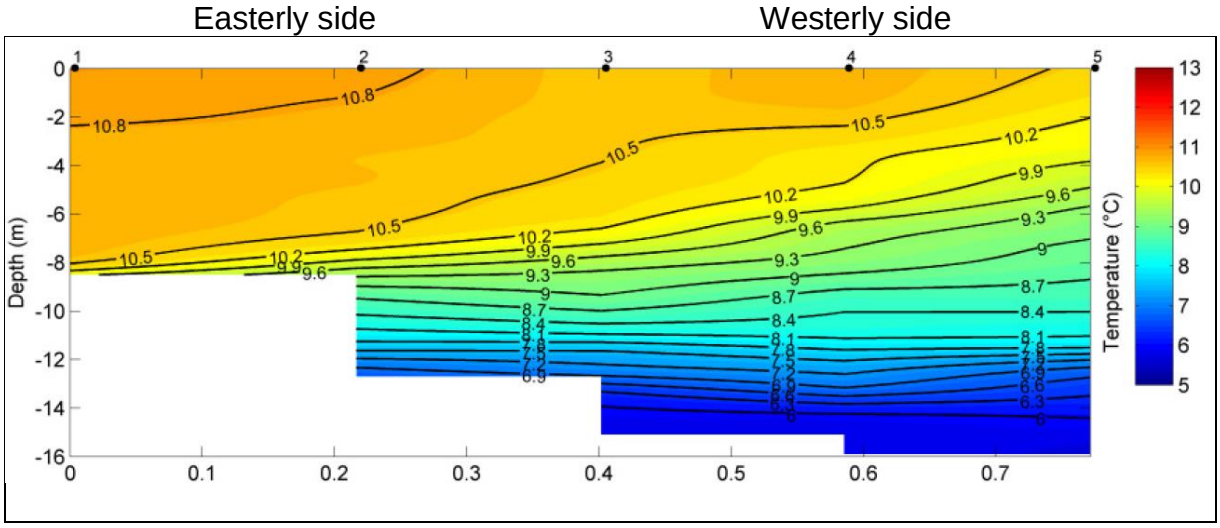


Figure 20: Temperature measurement in the Friedrichsort narrows on 4 May 2012

The circulation pattern is reflected in the water temperatures of the Kiel Firth. Accordingly, the inflowing colder water on the bottom replaces the receding warm water on the surface. Here, the inflowing water at the bottom has a temperature of about 6°C and the surface water of more than 10°C to a depth of about 8 m. The fresh west winds drove the warm surface water to the eastern bank and in compensation the ascended colder water to the western bank.

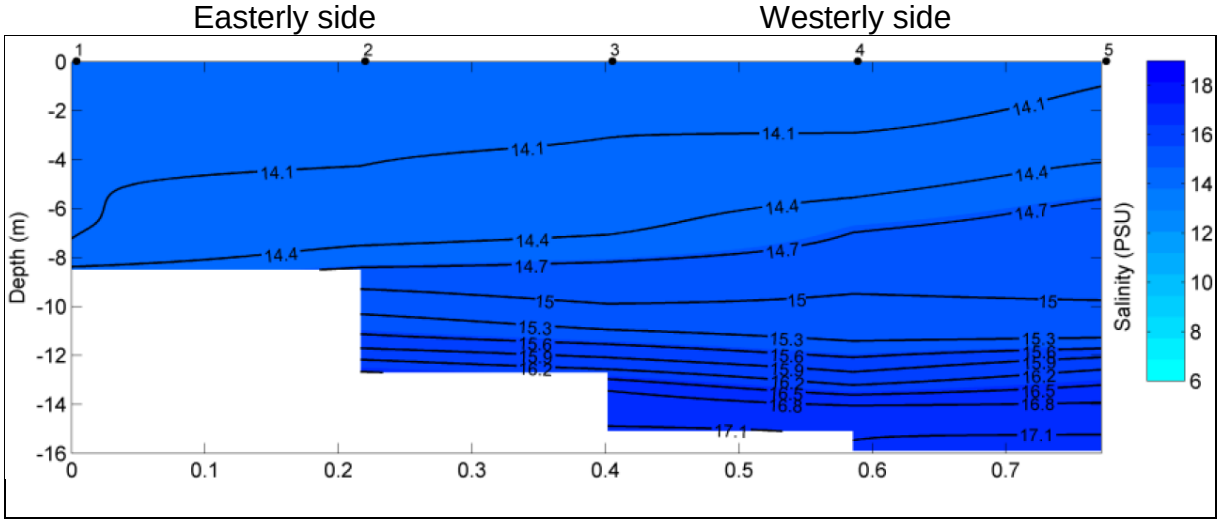


Figure 21: Salinity measurement in the Friedrichsort narrows on 4 May 2012

The wind-induced circulation pattern is confirmed by differing salinity in the depth layers. However, a degree of variation must be factored in due to inflowing fresh water from the River Schwentine, inflowing cold water from the power plant in Kiel, and wind-induced surface currents.

The BAW operates a Baltic Sea model. The present grid width of one element in the Kiel Firth is about 100 m and a current value is calculated for each one. This grid spacing would be too great for an accurate assessment of the current patterns in the Friedrichsort narrows. To do that, the grid width would need to be fine-tuned by a factor of three and the model's parameter control data included. At present, the BAW has neither the need nor resources for this sea area. The computations, data editing, and reporting would take two to three weeks at least and can only be scheduled with the numerical model experts well in advance.

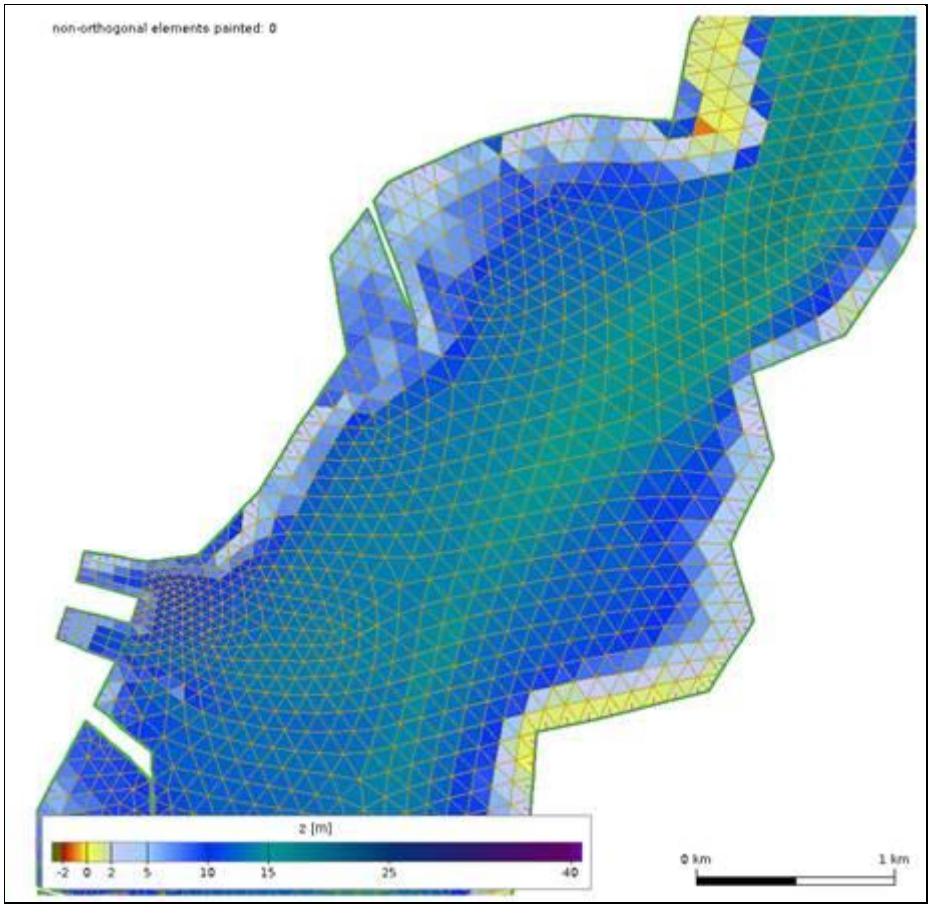


Figure 22: BAW grid model, Kiel Firth

The BSH circulation model's resolution in the Friedrichsort narrows is 900 x 900 m, which means that the conditions in the Kiel Firth are only poorly recorded. Even though it is not possible to compute details of the current in the Kiel Firth, it is at least possible to recognise that the currents were generally very weak in this region at the time of the collision. Inasmuch, the current had no significant impact on the course of the collision.

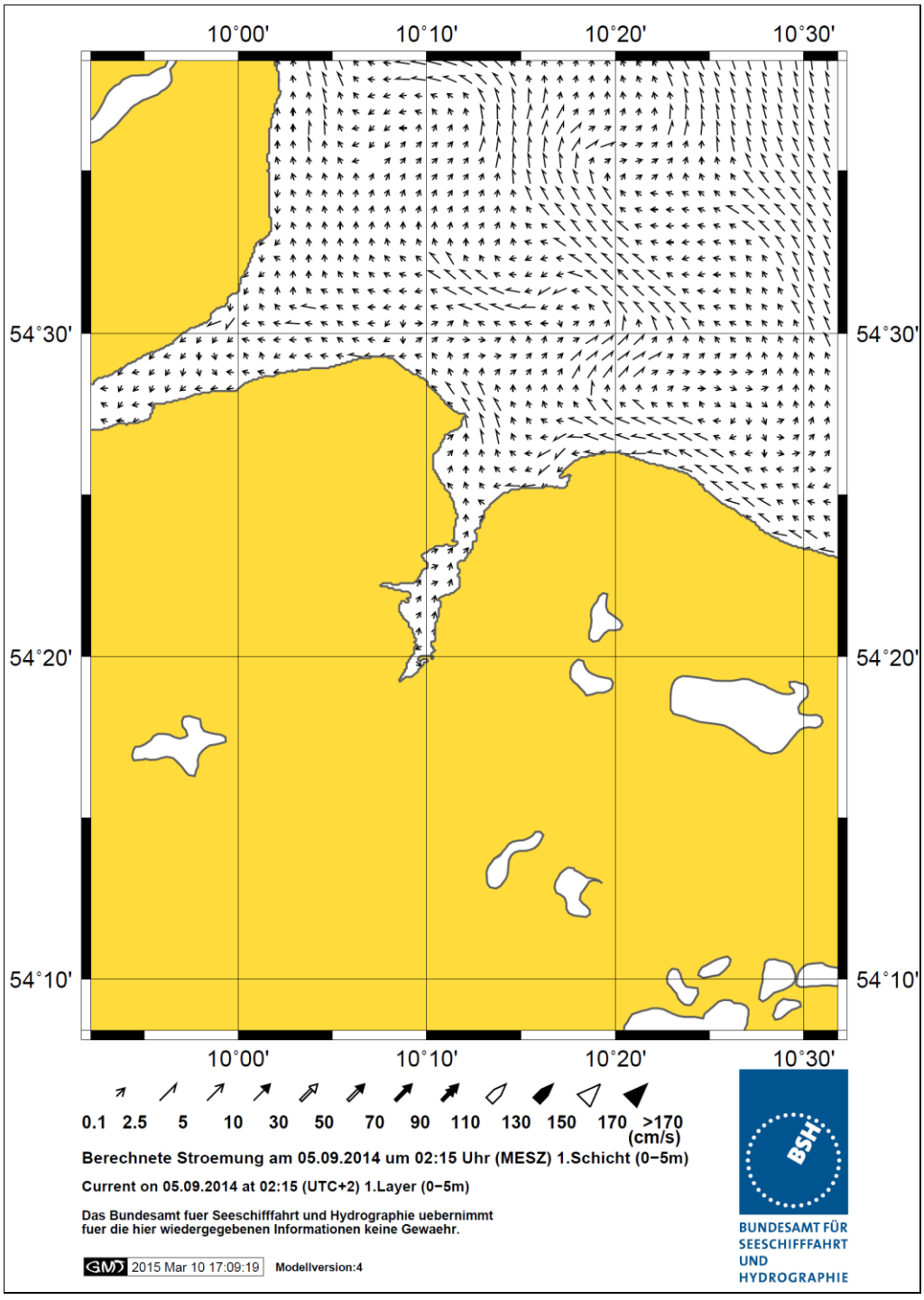


Figure 23: BSH model showing the computed current

According to the BSH's model, the strength of the north-easterly setting current was no more than 10 cm/s. The BSH's Ostsee-Handbuch (sailing directions for the Baltic Sea) 20031 specifies a maximum current velocity of 2.5 nm/h for the Kiel Firth in the Friedrichsort narrows. An outgoing current reportedly forms in south to westerly winds and an inflowing current in north to easterly winds. The most frequent variations in the water level reportedly occur in autumn and winter. They rise up to 1.5 m in north-westerly to south-easterly winds, peaking in north-easterly winds, and drop up to 1.5 m in south-easterly to north-westerly winds, peaking in stormy south-westerly winds.

These statements are very broad and too imprecise for an assessment of the course of the accident. The second wind-induced circulation model measured by Kiel University is not mentioned here. The BSH believes that for this problem area a model resolution of 20-50 m would be needed to arrive at sound results. However, high resolution is helpful only if all the parameter control data are correct and the model computes for an extended period. Only then is it possible to demonstrate that it works for the problem area. Several months would be needed to set up and test a model for the Bay of Kiel.

5 Conclusions

The collision at 0211 in good visibility, easterly winds of 4 Bft and a, probably, weak northerly setting current off the Friedrichsort beacon in the Kiel Firth is primarily attributable to the track of each vessel not being rendered on her electronic chart display appropriately for the situation. The recorded AIS data did not permit accurate determination of the scene of the collision. There was evidently a GPS error. The officer in charge of the navigational watch on each vessel failed to verify the GPS positions displayed with another system, such as radar, or visual bearings. The two officers in charge of the navigational watch relied on the positions displayed on the electronic chart and primarily focussed on the visual collision prevention whereas the RMS BREMEN had the advantage of having two nautical officers on the bridge, one of which was deployed as helmsman and steered the RMS BREMEN maintaining the course stability. It is likely that the FRANCISCA, with only one watch officer on the bridge, was alternately steered manually and with the heading control system (automatic pilot), respectively. The headings were more unstable than on the RMS BREMEN.

The RMS BREMEN kept close to the red light buoy 10 in the Friedrichsort narrows. However, the statements do not indicate whether the vessel also followed the so called buoy line parallel to the aft red light buoy 12 and whether the lights were verified visually by means of the electronic chart and the radar, respectively. It is unclear how the FRANCISCA was navigated and steered. A course alteration with the automatic pilot at a narrow passage would, depending on the setting of the parameters, could possibly be carried out not fast enough. The COG-vector directed to the south in figure 5 of the electronic chart suggests this. However, it would be also possible that a lower rudder effect was solely achieved through the speed reduction of the FRANCISCA and thus the COG-Vector occurred. According to the statement given by FRANCISCA, this manoeuvre was initiated during the course alteration abeam the lighthouse Friedrichsort, when the course should be altered from 187° to 213° and the collision occurred. The distance to the lighthouse could not be determined.

According to the damage pattern, both vessels scratched alongside each other in an acute angle. An able bodied seaman on board the FRANCISCA claimed to have seen two top lights and the red sidelight of the RMS BREMEN shortly before the collision. This is only possible if the vessels were in an more obtuse angle to each other before. According to the statements given by the FRANCISCA, a course alteration to port carried out by the RMS BREMEN was said to have been noticed. Thereby the acute collision angle might have occurred in order to avoid greater damage on the RMS BREMEN. According to the statements made on the RMS BREMEN, the top lights and the green side light of the FRANCISCA were said to have been in sight in at a distance of 0.5 nm from the lighthouse Friedrichsort. This was dead reckoned about 3 min. before the collision and absolutely possible. According to the AIS recordings which have to be assessed with reservation, the FRANCISCA changed her heading (HDG) temporarily to approx. 170°, but then turned abruptly back to 190° in order to turn to starboard to carry out the intended

course alteration to 213°. It is not possible to determine the exact scene of the collision by means of the recordings. Judging by the position indications of the RMS BREMEN at 0208 the accident would have occurred at 0211 dead reckoned ahead roughly abeam of the lighthouse Friedrichsort. But, according to a statement of RMS BREMEN, this was said to have been the last chance for the FRANCISCA to initiate a safe evasion manoeuvre.

However, it is to be noted, that the recorded GPS data are inconsistent. The recorded heading might at least have been realistic. They are taken from the gyro compasses and a heading transmitter, respectively. Recordings at an interval of one second or less would be required for a better assessment of the course stability on both vessels.

The BSU was only able to narrow down the scene of the collision (see Fig. 3). According to the GPS data-based AIS recordings, the vessels passed each other at some distance. The recorded positions could not be verified by another coastal system. The vessel traffic service did not save recorded radar images in the Kiel Firth on a long-term basis, meaning they were already overwritten at the time of the investigation and could not be reproduced.

It was not possible to determine reliably where the GPS error occurred. The BSU did not have measurement data for the GPS receivers on board. Neither vessel was equipped with a voyage data recorder (VDR). As a result, it was not possible to assess received GPS data. A type-tested GPS receiver was on board each vessel. They should have issued a warning if the HDOP value (horizontal dilution of position) exceeded four. With a 95% probability (2 drms), the accuracy of the received GPS positions is 8-13 m and up to 3 m in the case of DGPS. DGPS receivers were not installed on board. The DGPS correction parameters measured on shore for the GPS system displayed no anomalies at the time of the accident. Moreover, the simulated satellite constellations of the GPS at the time of the accident were normal with the exception of one satellite failure.

The GPS or other GNSS signals received are at microwatt level at the receiving antenna and very weak as compared to terrestrial transmitters like LORAN with a transmission output of 250 kilowatts. Consequently, shadowing of antennas by a ship's superstructure is quite possible. However, damaged antenna cable shielding may also cause interference. It was not possible to find any evidence of manipulation by interfering transmitters (jamming, spoofing). Vessel traffic services along the coast of Germany are now equipped with systems that superimpose AIS targets with radar targets. This makes it possible to verify the position of a ship in real time using a second independent system.

This accident shows that it is precisely the growing use of electronic charts that makes it necessary to verify the position of a ship at sea using all available means continuously.

The two vessels only had the minimum safe manning stipulated by the flag State of six seamen on board. It was proven that the hours of rest were not adhered to on the FRANCISCA and only the chief officer manned the bridge at the time of the accident. However, there was no indication that the chief officer was fatigued at the time of the accident. His lookout was on deck with a seaman making preparations for entering the Kiel lock. It is possible that the presence of a lookout on the bridge would have influenced the course of the accident during the course alteration.

As found during the flag State control on the FRANCISCA, the small number of crew members on the two vessels provides very little potential for manning the stations in compliance with the required hours of rest and work in a two-watch system. Consequently, owners are urged to provide sufficient personnel for their ships. Having said that, the master also has a responsibility to pay attention to hours of rest and work vis-à-vis the crew, otherwise severe fines may be imposed on him. He must inform the owner in good time if there is a possibility that hours of work will be exceeded or hours of rest will not be complied with.

The current indications of the BSH refer to a pattern of 900*900 m in the model used. There, a rather weak northerly current was altogether calculated and transferred to the Friedrichsdorfer narrow. The actual current could not be determined by the BSU. An increase of the resolution to 20*20m would increase the processor load of the BSH to about 10.000. This would require new investments, only having an effect in 3-5 years.

6 Safety recommendations

6.1 Waterways and Shipping Authority (WSA) Lübeck

The BSU recommends that the WSA save recorded audio, video, radar and AIS data, handwritten records, and other relevant data of their traffic safety systems in the event of a marine casualty for the purposes of the Maritime Safety Investigation Act (SUG) for ten years in a public format that enables reproducibility in a marine casualty investigation using commercially available software.

6.2 Federal Maritime and Hydrographic Agency (BSH)

The BSU recommends that the BSH, as publisher of official navigational bulletins, make available a circulation model of the Kiel Firth with a resolution of up to 100 m and at least 20 m for the Friedrichsdorfer Narrow and the area of the Kiel Canal on the Internet and revise the information in its sailing directions for this area.

6.3 Owners, operators, and ship's commands of the FRANCISCA and RMS BREMEN

The BSU recommends that in respect of manning levels, owners and operators take technical measures to facilitate work for their watch keepers on the bridge and man ships sufficiently for the requirements of the area of operation and the navigational equipment on the bridge. These include the verification of global navigation satellite system (GNSS) positions by such appropriate means as the installation of DGPS receivers, the installation of a second different GNSS like GLONASS, and the superimposition of AIS with radar targets.

The BSU recommends that officers in charge of the navigational watch on the bridge continuously verify the position of the ship in coastal waters with all available means using visual bearings and two independent systems, i.e. GNSS, radar units, and involve the lookout at night time, in particular.

The BSU recommends that the master of the FRANCISCA review the hours of work and rest of his crew in accordance with the International Labour Organization's Maritime Labour Convention, 2006, and, if a shortage of manpower is foreseeable, inform the owner and ensure the situation is remedied.

7 SOURCES

- Enquiries of Waterway Police (WSP) Kiel
  - Vessel Traffic Service Travemünde

- Written statements
  - Ship's command
  - Owner
  - Classification society

- Witness accounts
  - Crews

- Expert opinion/technical paper
  - Federal Maritime and Hydrographic Agency (BSH)
    Operational models, Dr. Frank Janssen
    Navigation systems, satellite navigation, Dipl.-Ing. Jochen Ritterbusch, Dipl.-Ing. Tobias Ehlers
  - Federal Waterways Engineering and Research Institute (BAW) Hamburg
    Dr.-Ing. Klemens Uliczka, Dipl.-Ing. Martin Wezel
  - Traffic Technologies Centre of the WSV, Koblenz, Michael Hoppe
  - Kiel University's Research and Technology Centre, West Coast
    Dipl.-Geol. Dr. Klaus Ricklefs
  - National Transportation Safety Board (NTSB), Washington, DC
  - Vesseltracker, Hamburg
  - Antigua and Barbuda W.I. Department of Marine Services and Merchant Shipping Inspection and Investigation Division, Bremerhaven

- Nautical charts and ship particulars, BSH

- AIS and radio recordings of Vessel Traffic Service Travemünde

- Photos from Hasenpusch in Hamburg, WSP Kiel